



Cyclotrons for Decay-At-Rest Neutrino Production

Jose Alonso
MIT



High Intensity 2ndary Beams Wkshp

April 18, 2013

Accelerator Collaborators and Participants*

- Collaboration Spokespersons:
 - Janet Conrad, MIT
 - Mike Shaevitz, Columbia
- Collaborating Laboratories (Support: Internal and MIT contracts)
 - Laboratori Nazionali del Sud (INFN-LNS), Catania, Italy
 - Luciano Calabretta, Alessandra Calanna, Daniela Campo, Luigi Celona, Santo Gammino, ...
 - Paul Scherrer Institute, Villigen, Switzerland
 - Andreas Adelmann, Jianjun Yang, Marco Schippers, ...
 - RIKEN, Wako, Saitama, Japan
 - Hiroki Okuno
- Industries (Support: Internal)
 - Best Cyclotron Systems, Vancouver BC
 - Bruce Milton, Todd Mawhinney, Francis Labecque, ...
 - IBA, Louvain la Neuve, Belgium
 - Yves Jongen, Willem Kleeven, Michel Abs, ...
 - AIMA, Nice, France
 - Pierre Mandrillon, Gerome Mandrillon
- Many Universities worldwide
 - See <http://www.nevis.columbia.edu/daedalus/collab/index.html>

* Principal funding provided by
NSF through MIT



Accelerator Physicists and Engineers Involved in the Cyclotron Development

Adriana Bungau, University of Huddersfield

Alessandra Calanna, MIT

Anna Kolana, University of Huddersfield/PSI

Andreas Adelmann, PSI

Bernard Gottschalk, Harvard University

Bill Barletta, MIT

Bruce Milton, Best, Inc.

Chris Tschalaer, MIT

Daniel Winklehner, Michigan State University

Daniela Campo, MIT

Eric Forton, IBA-Research

Francis Labrecque, Best, Inc.

Hiroki Okunu, RIKEN

Hywel Owen, University of Manchester

Jerome Mandrillon, AIMA

Jerry Nolen, Argonne National Laboratory

Jianjun Yang, MIT/PSI

Jose Alonso, MIT

Joseph Minervini, MIT

Larry Bartoszek, Bartoszek Engineering

Leandro Piazza, INFN-Catania

Luciano Calabretta, INFN-Catania

Luigi Celona, INFN-Catania

Lukas Stringelin, PSI

Mario Maggiore, INFN-Catania

Michel Abs, IBA Research

Mike Seidel, PSI

Roger Barlow, University of Huddersfield

Santo Gammino, INFN-Catania

Sebastiano Albergo, CSFSM-Sicily, Italy

Tim Koeth, University of Maryland

Todd Mawhinney, Best, Inc.

Willem Kleeven, IBA-Research



Topics

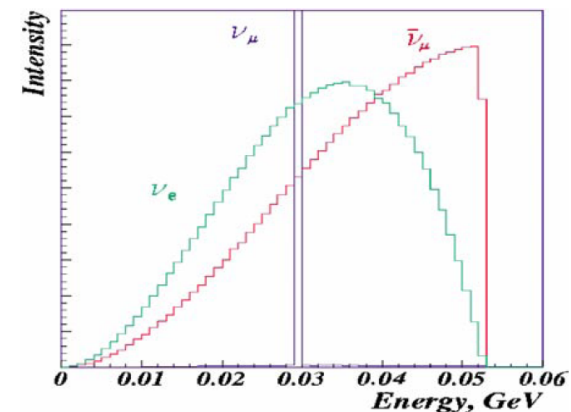
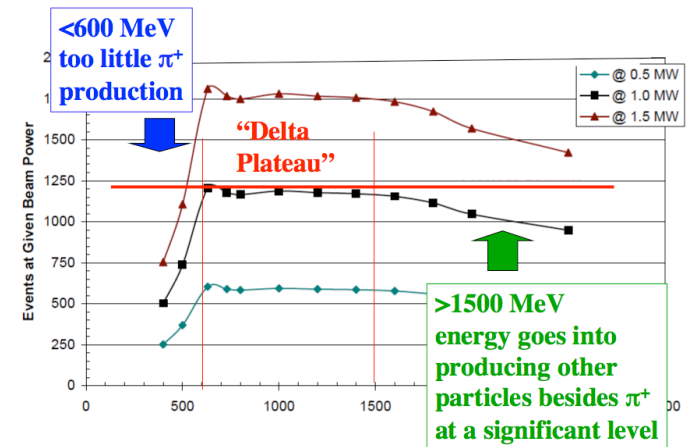
- Decay-At-Rest neutrino experiments
- Accelerator concepts: H_2^+
- Requirements and challenges
- Progress, Plans and R&D needs

Decay-At-Rest Experiments:

1: Pions from 800 MeV Protons

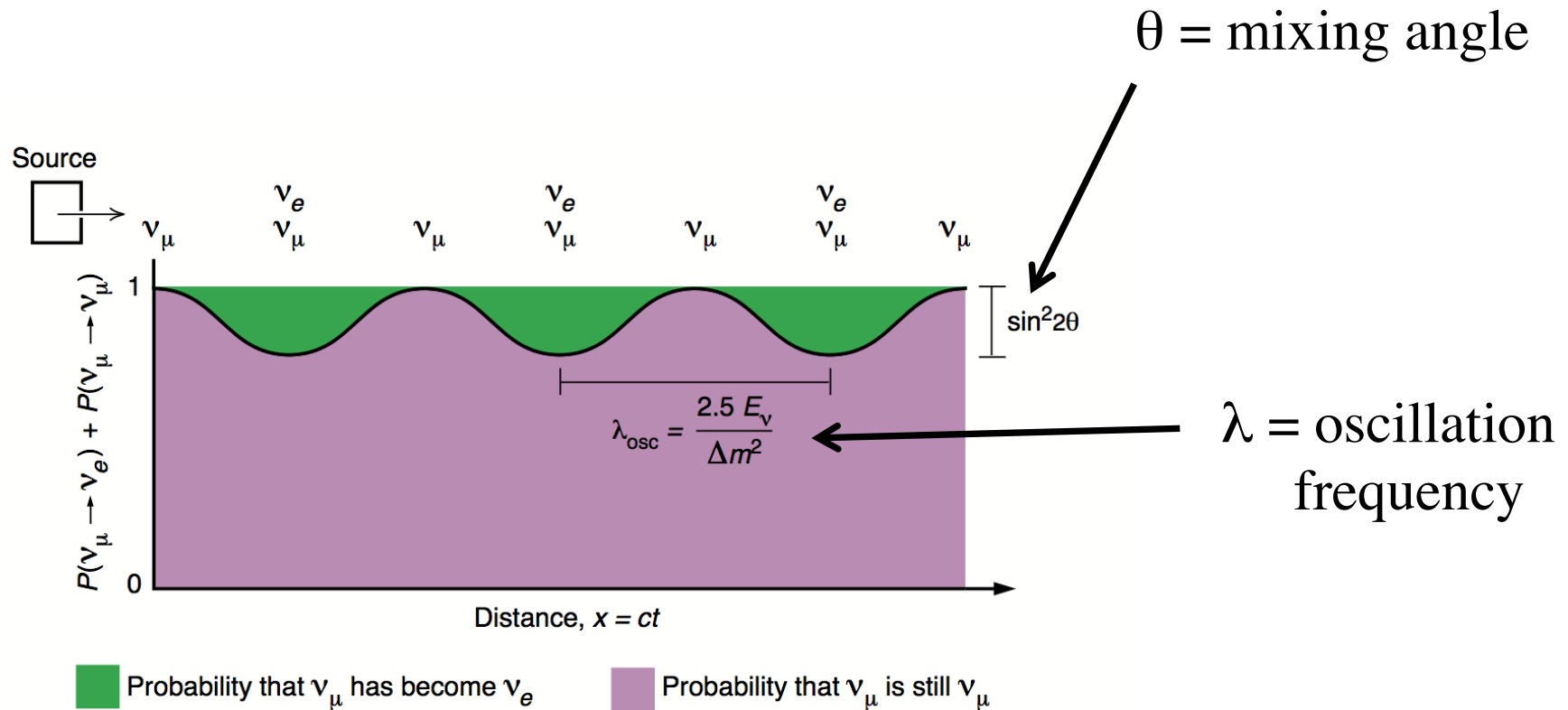
- Energy comfortably above threshold
- Pions produced at low enough energy to stop before decaying
- π^- absorbed prior to decay
- Well-defined neutrino spectrum
- Mostly devoid of $\bar{\nu}_e$
 - $\bar{\nu}_e$ in primary beam $\sim 10^{-4}$
- Sensitive to appearance of $\bar{\nu}_e$
 - ... oscillation from $\bar{\nu}_\mu$
- Detection: Inverse Beta Decay

$$\bar{\nu}_e + p \rightarrow e^+ + n$$
 - (need detector with high fraction of free protons: water or liquid scintillator)

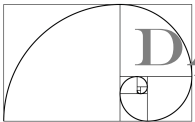


G. Karagiorgi's talk yesterday

Oscillations of Neutrinos



NOTE: $\lambda/E \sim 1/\Delta m^2$

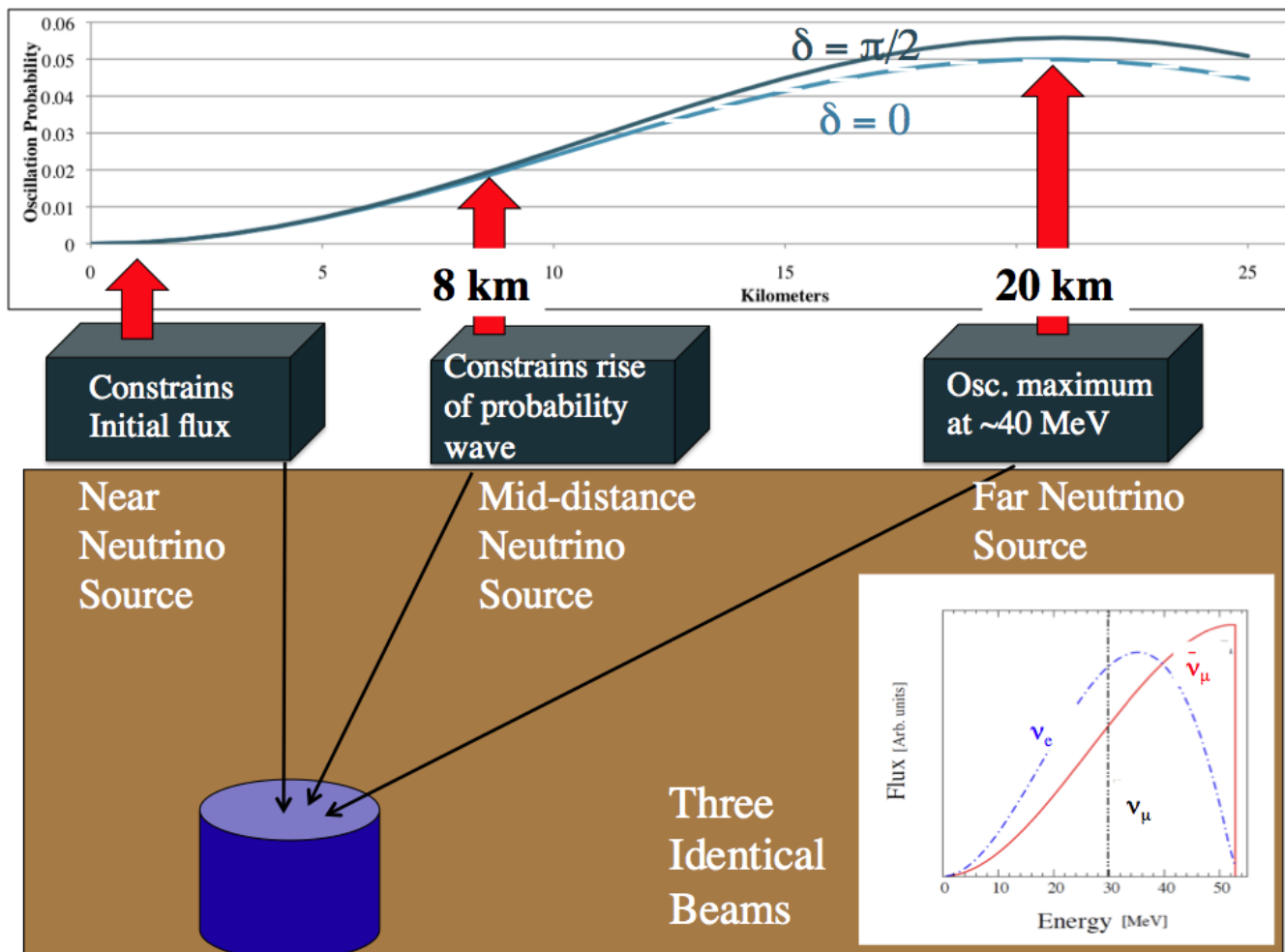


DAEδALUS

DAEδALUS Configuration

Good sensitivity to
CP violation δ

Neutrino Oscillation:
 $\lambda/E \approx 1/\Delta m^2$

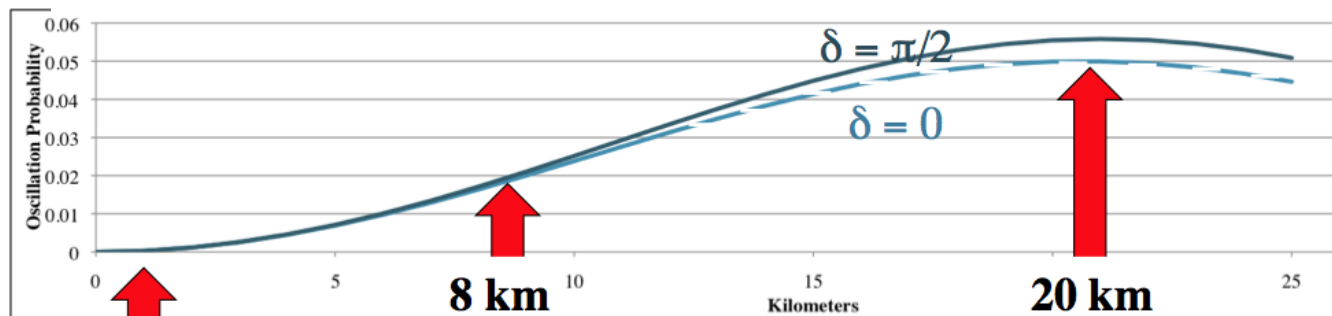
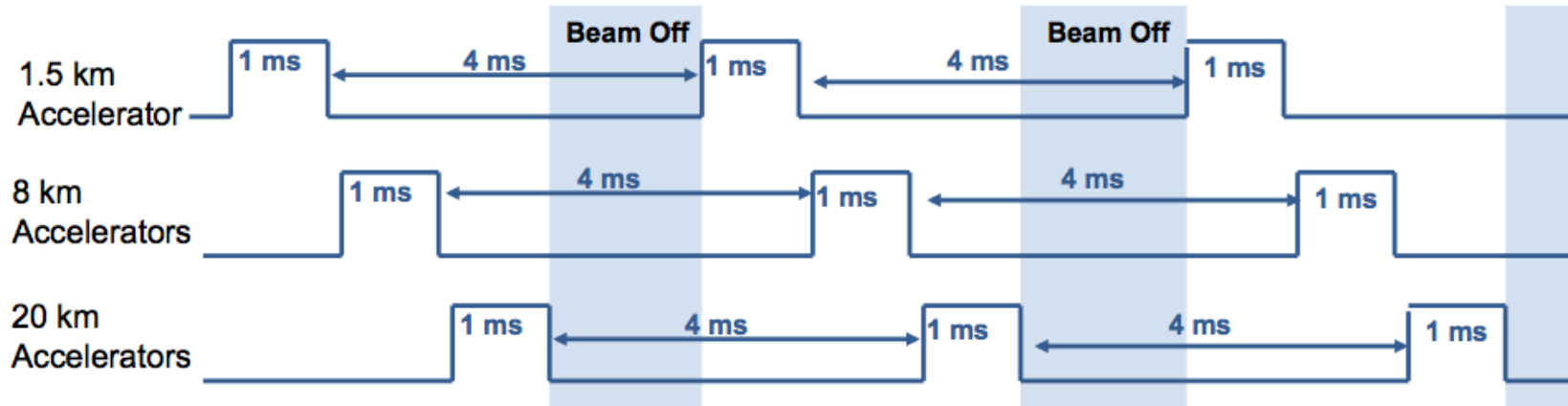


1000 km / 2 GeV
(LBNE)
20 km / ~ 40 MeV
(DAEδALUS)

Complementarity!

LBNE in ν mode
DAEδALUS in $\bar{\nu}$

Great improvement
In statistics



Constrains
Initial flux

Constrains rise
of probability
wave

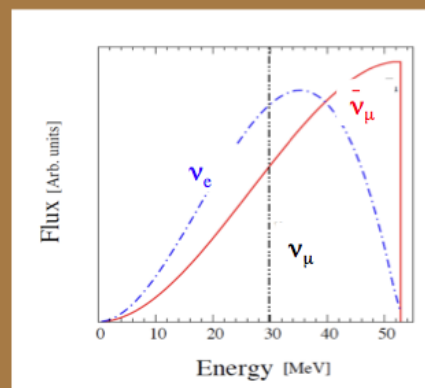
Osc. maximum
at ~ 40 MeV

Near
Neutrino
Source

Mid-distance
Neutrino
Source

Far Neutrino
Source

Three
Identical
Beams



1000 km / 2 GeV
(LBNE)
20 km / ~ 40 MeV
(DAE δ ALUS)

Complementarity!

LBNE in ν mode
DAE δ ALUS in $\bar{\nu}$

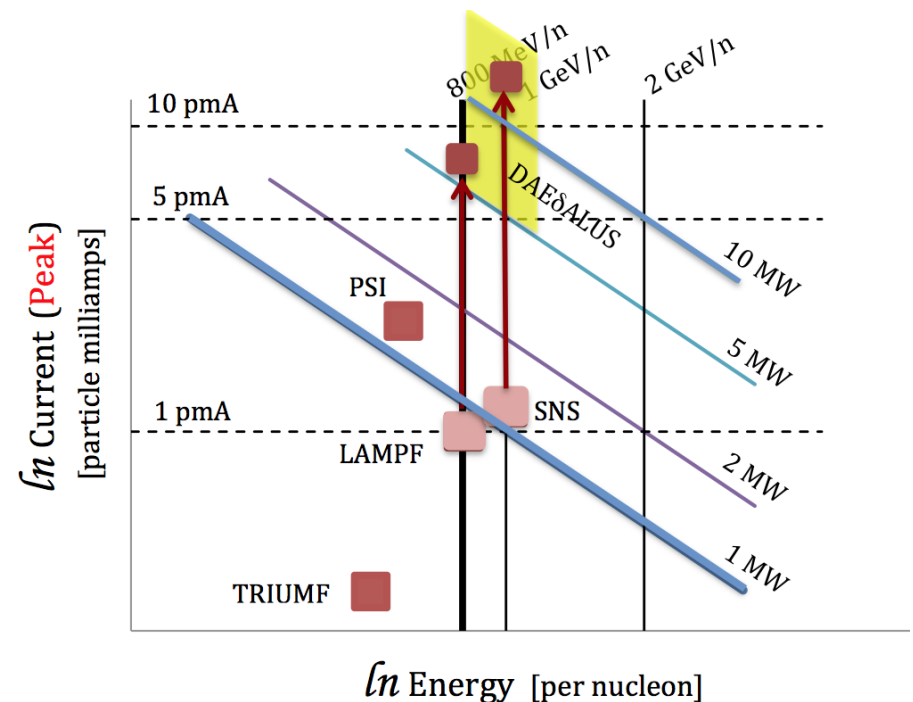
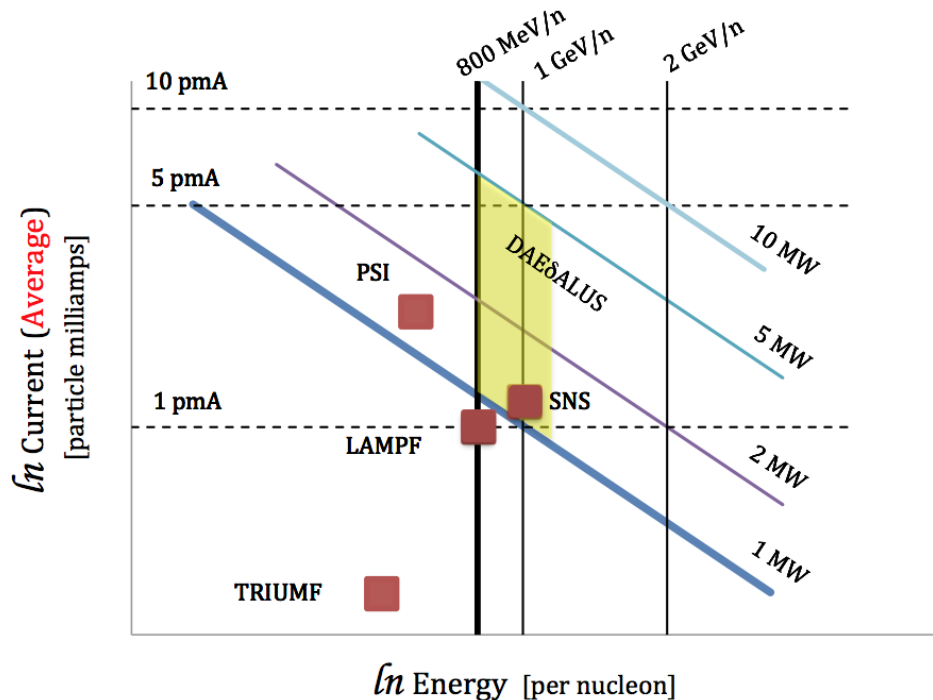
Great improvement
In statistics

Accelerator Requirements

- Three “identical” sources
 - 800 MeV protons on target
 - Isotropic neutrino spectra requires greater flux at longer baselines
 - Not quite $\{r^2\}$, due to increased signal strength
 - Proton power on target (average):
 - Near site 1 MW
 - Mid site 2 MW
 - Far site 5 MW
 - Based on matching data rates from LBNE, and statistics for a ~10 year experiment
 - Peak current: ~10 mA
 - Size and costs must be kept as low as possible!

Implications of Timing Constraints

- Typical duty factor for each station: 20%
 - Only one machine operating at a time
 - Need time off for calibration, background

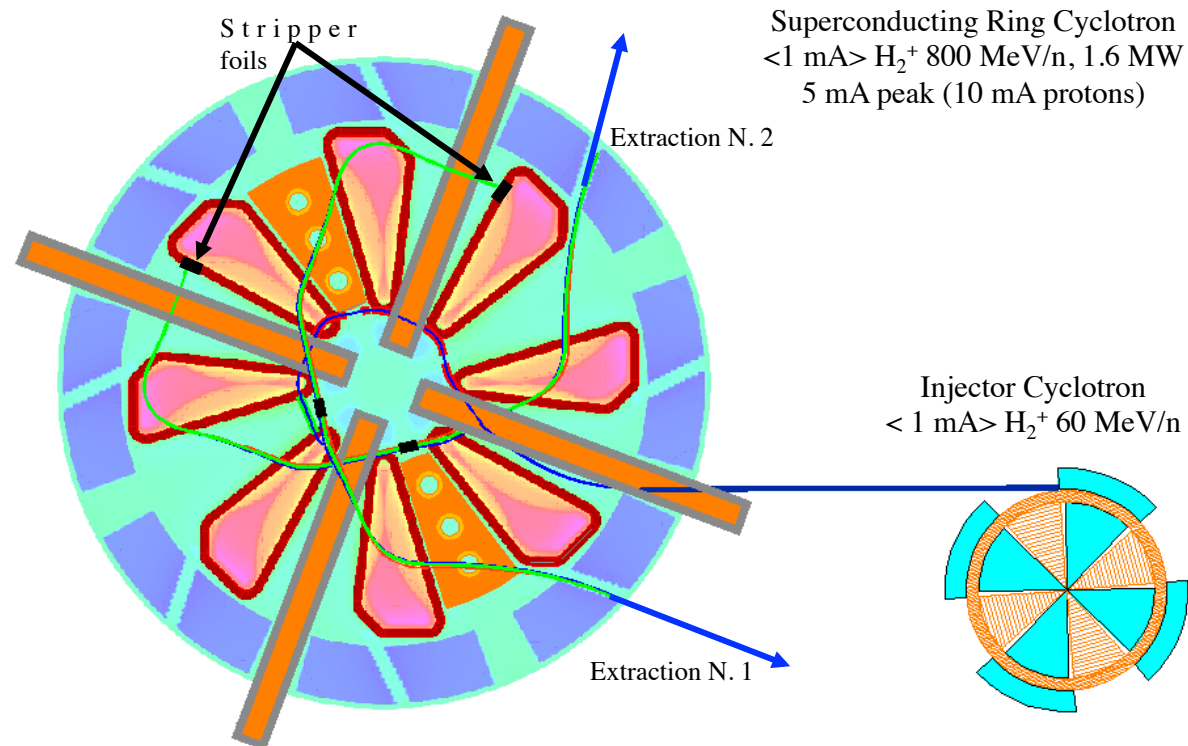


Concept: H_2^+ Cyclotrons

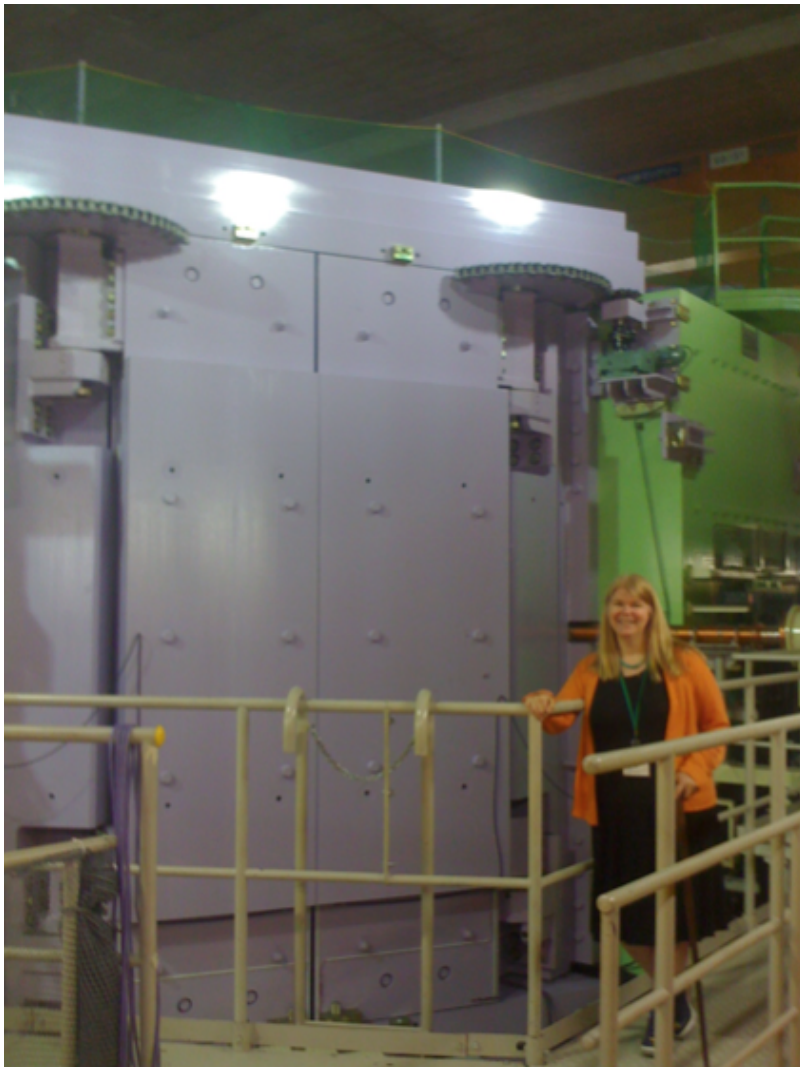
- Luciano Calabretta: INFN-Catania
- arXiv: 1107:0652

H_2^+ advantages:

- Lower space charge at injection
- Stripping extraction

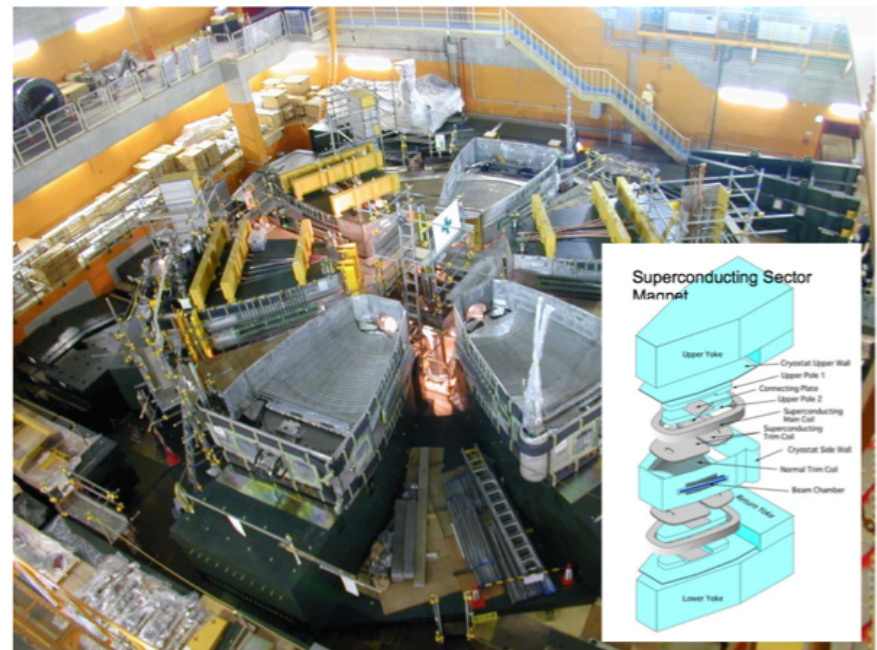


Status of SRC Concept



RIKEN SRC:
Engineering Existence Proof!

RIKEN K2600 SUPERCONDUCTING RING CYCLOTRON

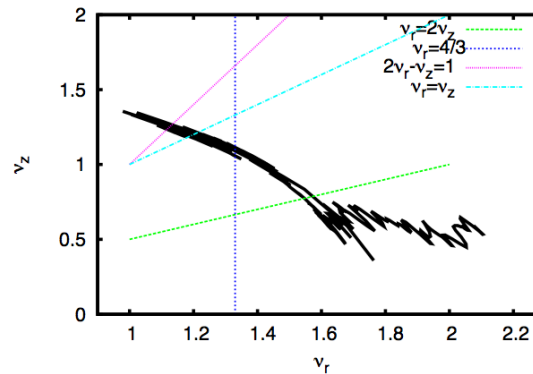
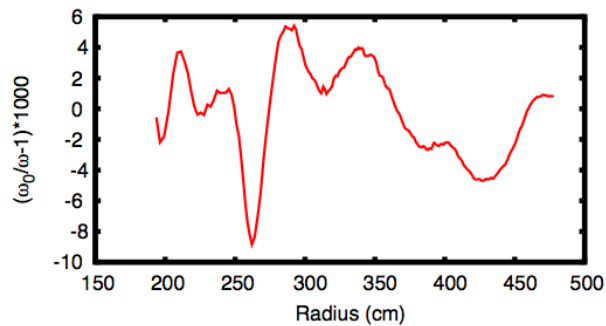


Completed November 2005 - the 140-ton cold mass cooled to 4.5K.

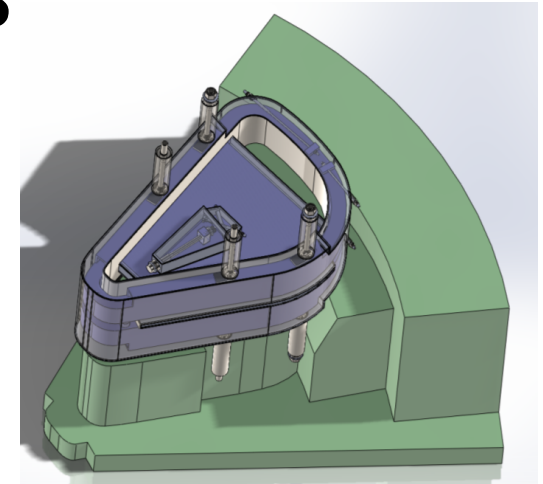
SRC Status

Beam Dynamics

Isochronicity ($\pm 0.4\%$)



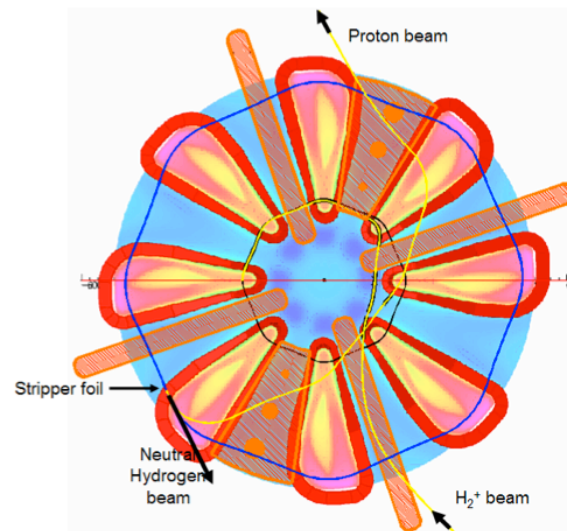
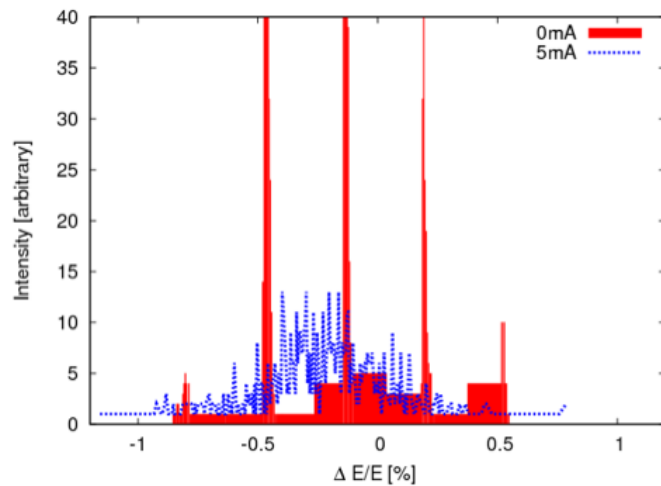
Tune diagram



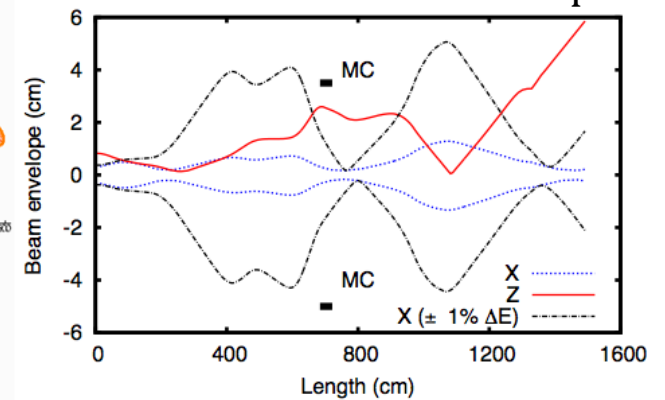
Engineering study of
coil/cryostat assembly
MIT (Minervini et al)
Nov 2012

EXTRACTION

Energy spread on stripper



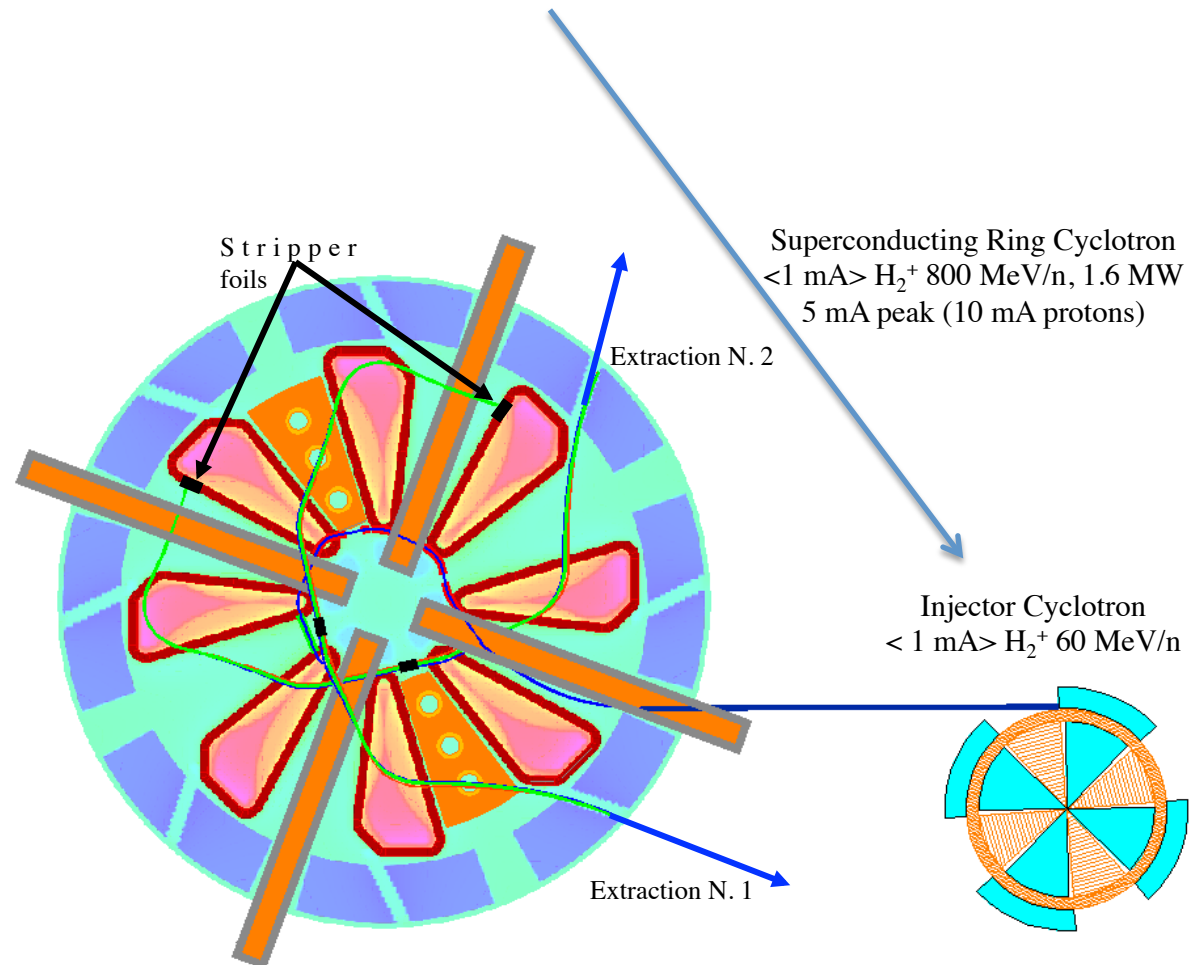
Extraction channel envelopes



Project Staging: Build Injector First

H_2^+ advantages:

- Lower space charge at injection
- Stripping extraction

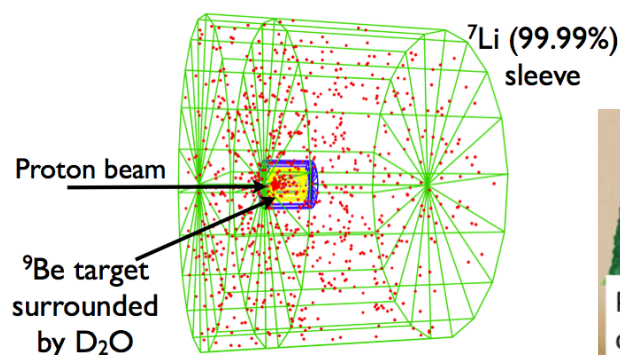


Injector Cyclotron: Basis for IsoDAR

Decay-At-Rest Experiments:

2. Beta decay of ^8Li from 60 MeV protons

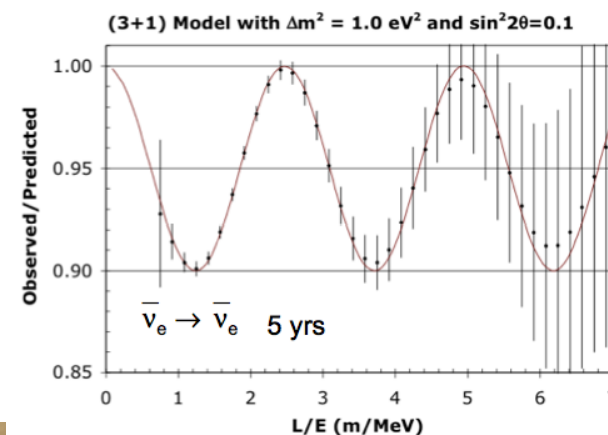
- $\bar{\nu}_e$ oscillation experiment at very short baseline
- Sterile neutrino search
 - $\Delta m^2 \sim 1 \text{ eV}^2$, $\lambda < 10 \text{ meters}$
 - Can see oscillations *within* detector!



Neutrons generated in Be target, ^8Li produced in very pure ^7Li blanket



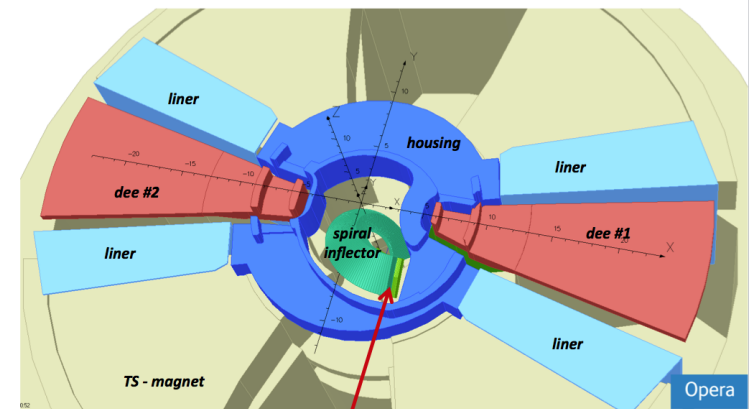
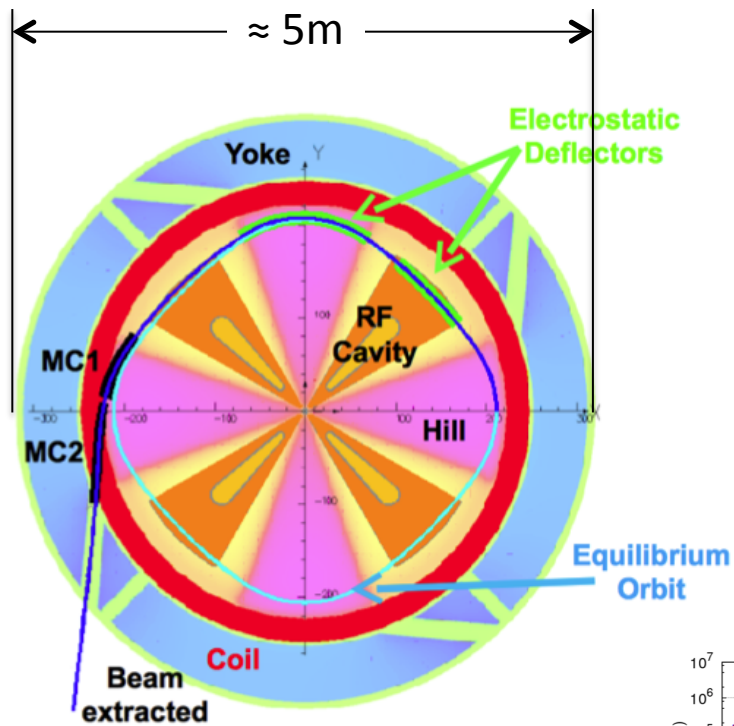
IsoDAR at KamLAND



G. Karagiorgi's talk yesterday

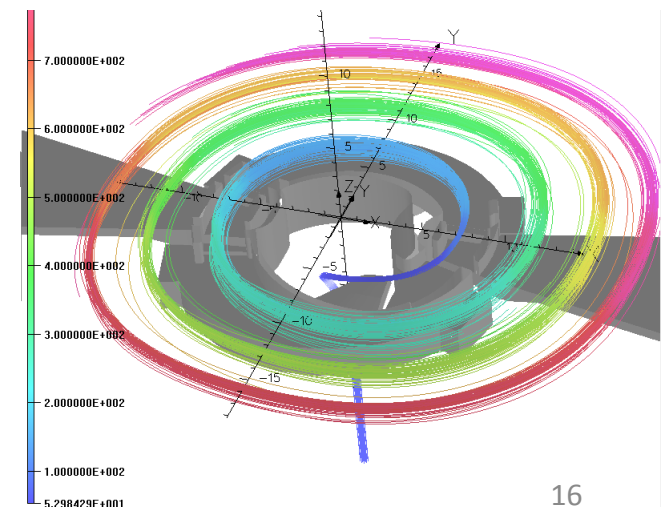
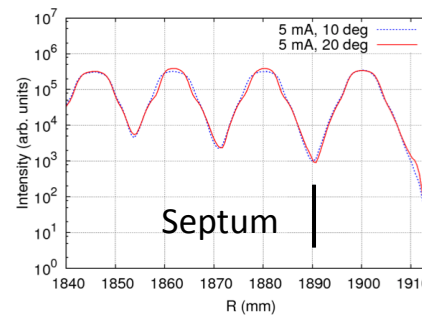
Injector Cyclotron Configuration

- Compact, axially-injected, septum extracted



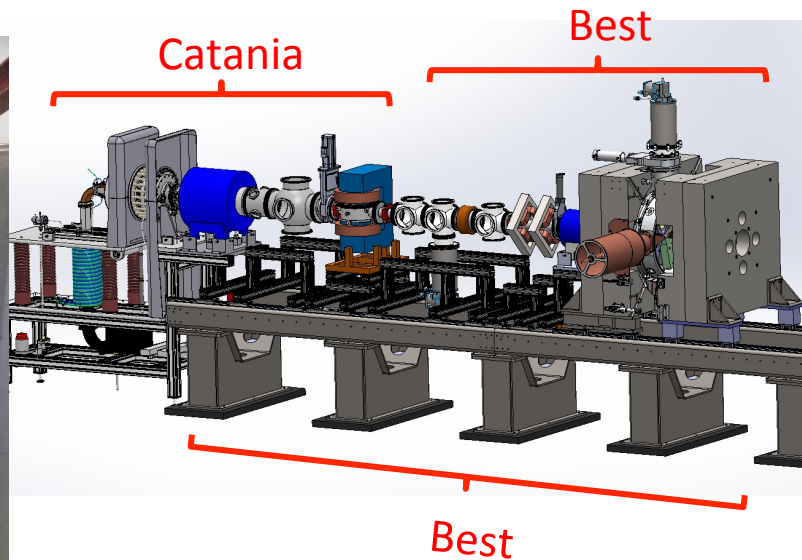
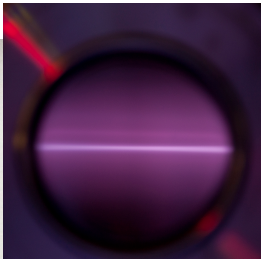
beam injection in the median plane

Turn separation at extraction

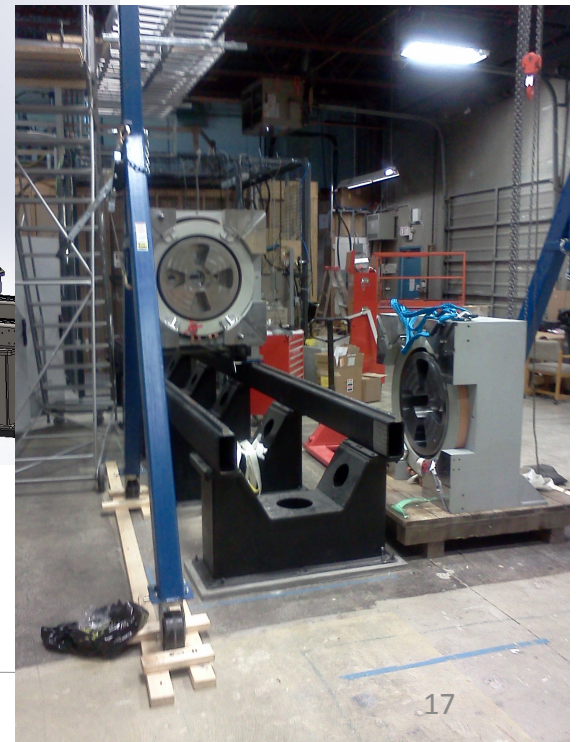


Challenges

- Space charge at axial injection
 - Being addressed this summer at Best Cyclotron Systems, Vancouver BC



High Intensity 2ndary Beams Workshop

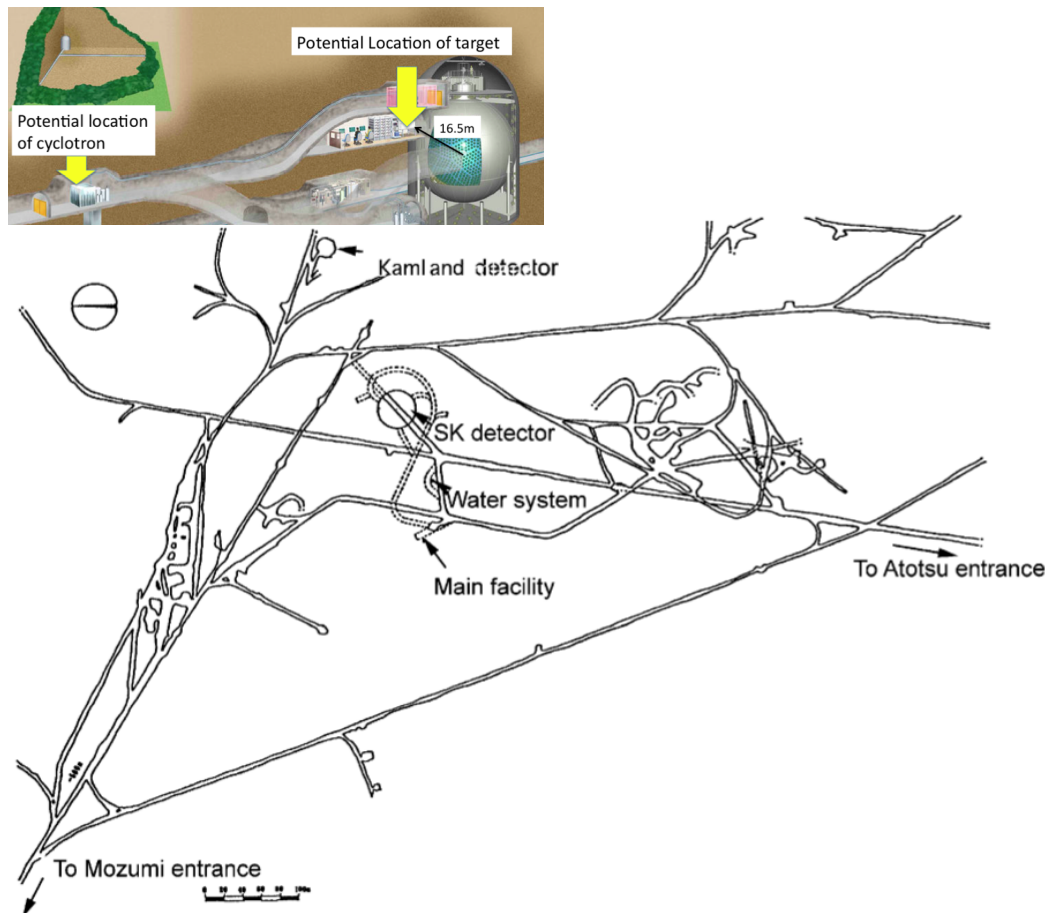


Roadmap for Central Region Tests

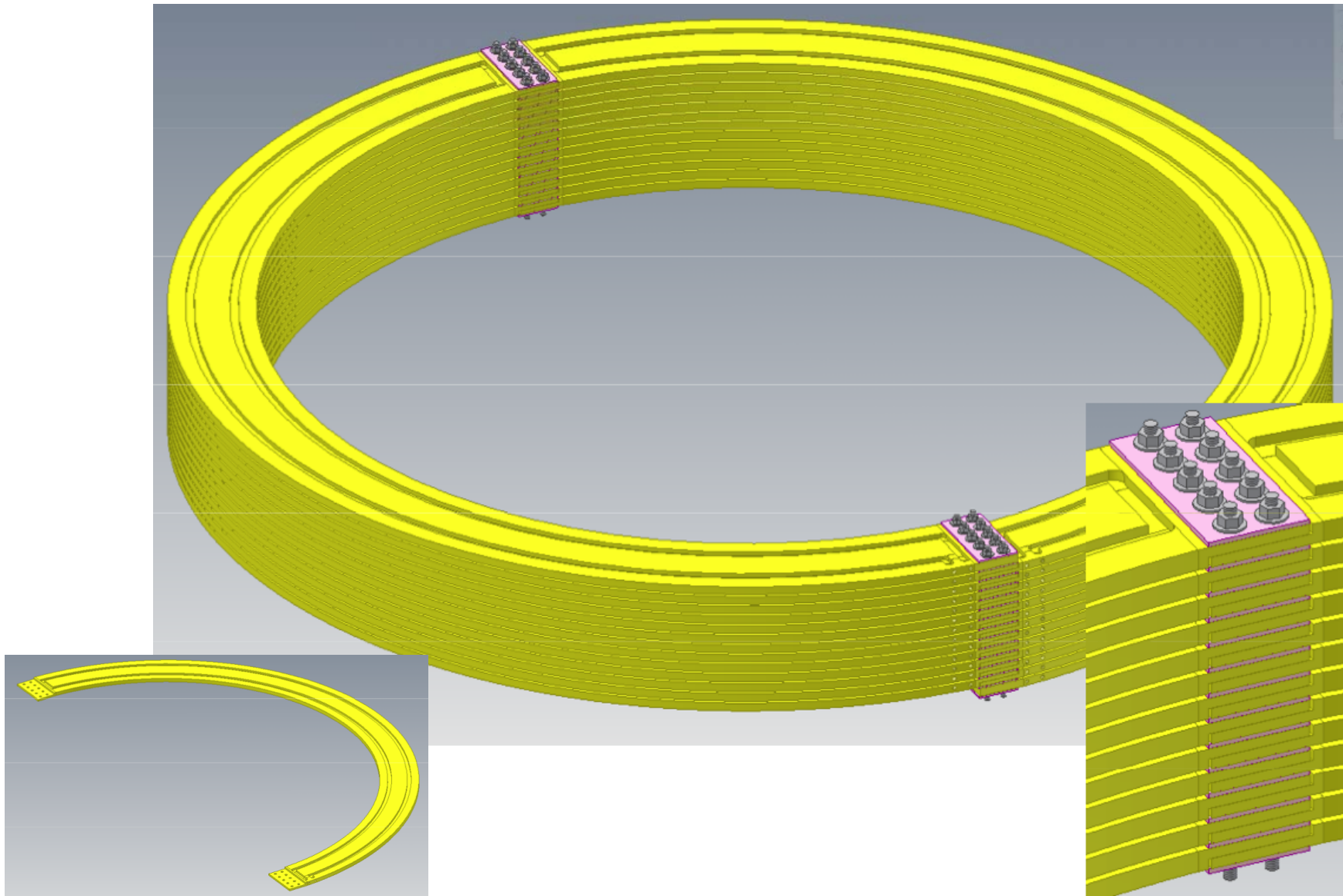
- Summer 2013:
 - Inflection tests will provide first experimental work with H_2^+
 - H_2^+ ion transport/purification
 - Buncher performance
 - Capture efficiency
- 2014 ff:
 - Prototype 28 MeV (4 MeV/amu) Catania test stand
 - Build on experience from Vancouver
 - Refined central region design
 - Benchmarking of OPAL space charge simulations for injection and low-energy acceleration
 - Cyclotron directly usable as isotope producer with alpha beams
 - IsoDAR design should follow directly

Assembly of Cyclotron at KamLAND

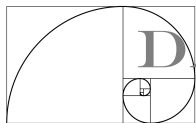
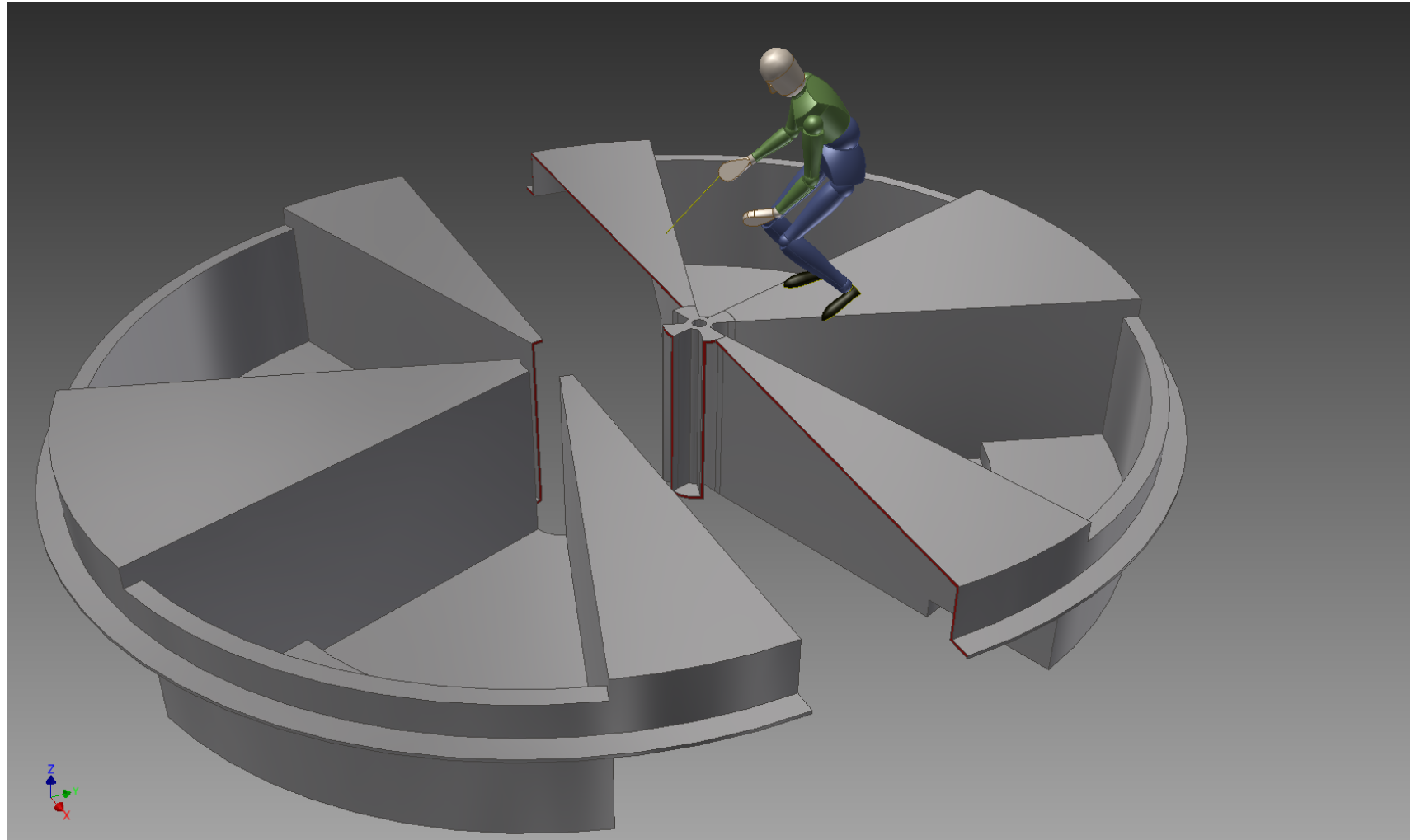
- Access does not allow transport of fully-assembled cyclotron



Coil Assembly Option



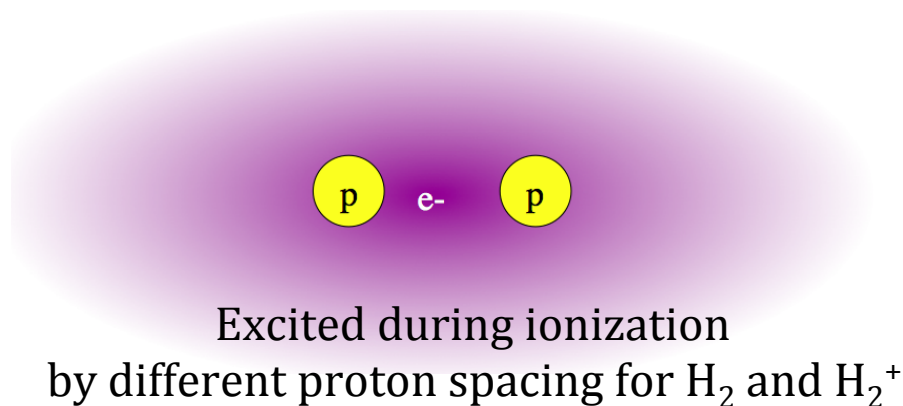
Vacuum Liner Option



DAEδALUS

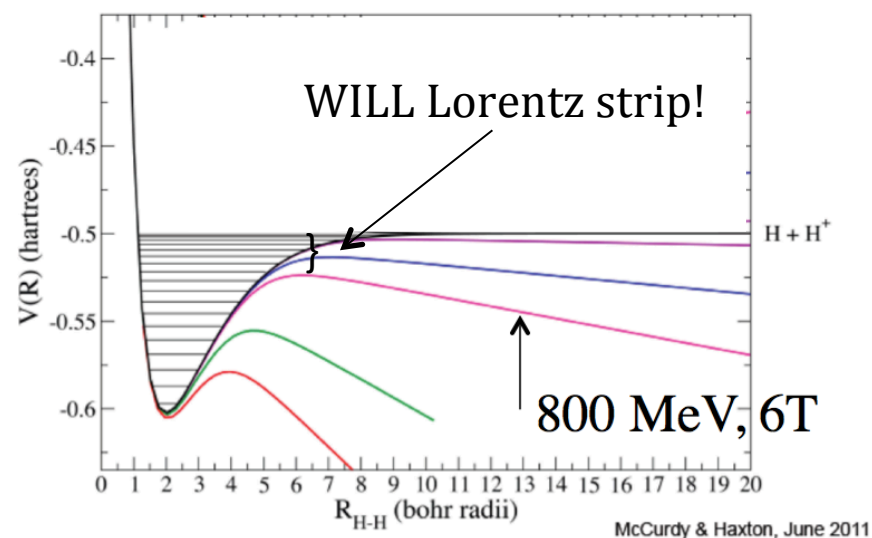
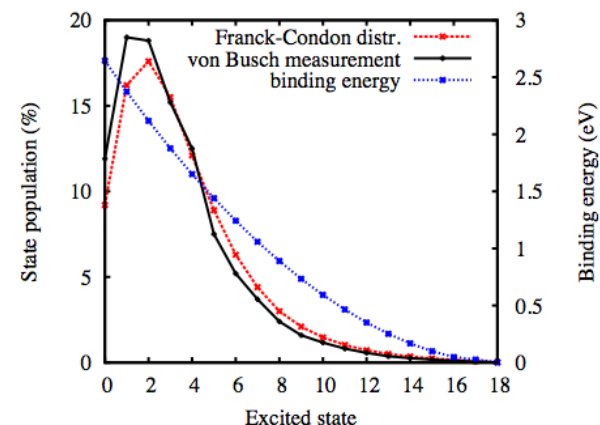
DAEδALUS Challenges

- H_2^+ Ion source: quenching vibrational states



NOT a problem for IsoDAR

Collaborating with ORNL Atomic Physics
BUT: Test Stand, connected to Holifield
is being shut down



Summary (1): Observations

- H_2^+ cyclotrons can be effective neutrino sources
 - Compact, cost-effective, modular
 - Other applications: Isotopes, ADS
- Best available beam-dynamics simulations indicate no show-stoppers
- Engineering studies and field experiences are encouraging

Summary (2): Roadmap

- Axial Injection Line and Central Region development
 - Tests in Vancouver, Spring/summer 2013
 - Second test in Catania, refined design, 2014
 - Point to final design of Injector central region
- Injector Cyclotron: Unit #1
 - Deployment of IsoDAR experiment
 - Requires further simulations, engineering studies
 - Looking for collaboration with private industry
 - ... producing world-class physics!
- Ring Cyclotron development
 - Need further simulations, engineering studies
 - Need prototyping of sector magnet
 - Studies of beam-loss mitigation (vacuum, injection, extraction)
- H_2^+ ion source development
 - Achieving required current levels of H_2^+ (~ 40 -50 mA CW)
 - Quenching of vibrational states (ORNL has capabilities that may disappear!)

Bibliography of DAE δ ALUS publications:

<http://www.nevis.columbia.edu/daedalus/docs/publications.html>